

**Washington State University**

Department of Mechanical and Materials Engineering  
Pullman, WA 99164-2920

227 FLC/100  
**COPY**

30/30

(509) 335-8654  
FAX: (509) 335-4662

RECEIVED

JUN 23 1995

OFFICE OF GRANT AND RESEARCH DEVELOPMENT

File 1

June 20, 1995

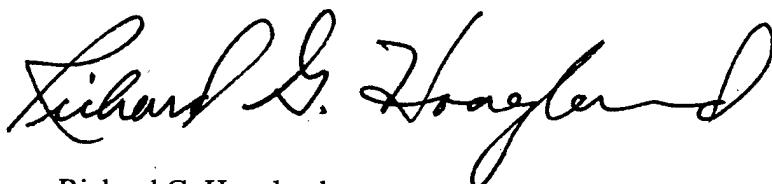
Dr. George R. Yoder  
Office of Naval Research  
CD 1131  
Materials Division, Engineering Sciences  
800 N. Quincy St.  
Arlington, VA 22217-5000

Ref: Grant N00014-93-1-0022 "Deformation and Fracture Mechanisms in Thin Films and Beryllium Intermetallics

Dear Dr. Yoder:

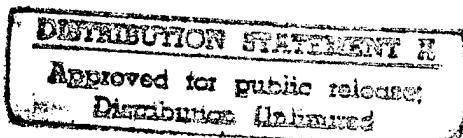
To our dismay we have discovered that the final report for the above-referenced grant had not been submitted and is overdue. Consequently, we have enclosed three copies of the final report for this grant. We apologize for the delay.

Sincerely,



Richard G. Hoagland  
Professor

cc: J. P. Hirth, Mecahnical and Materials Enggr  
C. Zuiches, Office of Grant  
and Resaerch Development





DEPARTMENT OF THE NAVY  
OFFICE OF NAVAL RESEARCH  
SEATTLE REGIONAL OFFICE  
1107 NE 45TH STREET, SUITE 350  
SEATTLE WA 98105-4631

IN REPLY REFER TO:

4330  
ONR 247  
11 Jul 97

From: Director, Office of Naval Research, Seattle Regional Office, 1107 NE 45th St., Suite 350,  
Seattle, WA 98105

To: Defense Technical Center, Attn: P. Mawby, 8725 John J. Kingman Rd., Suite 0944,  
Ft. Belvoir, VA 22060-6218

Subj: RETURNED GRANTEE/CONTRACTOR TECHNICAL REPORTS

1. This confirms our conversations of 27 Feb 97 and 11 Jul 97. Enclosed are a number of technical reports which were returned to our agency for lack of clear distribution availability statement. This confirms that all reports are unclassified and are "APPROVED FOR PUBLIC RELEASE" with no restrictions.
2. Please contact me if you require additional information. My e-mail is *silverr@onr.navy.mil* and my phone is (206) 625-3196.



ROBERT J. SILVERMAN

**Final Report**

**on**

**DEFORMATION AND FRACTURE MECHANISMS IN  
THIN FILMS AND BERYLLIUM INTERMETALLICS**

**Conducted under**

**Grant N00014 - 93 - 1 - 0022**

**by**

**John P. Hirth  
Richard G. Hoagland**

**1995**

**Washington State University  
Pullman, WA 99164**

**19970717 084**

**DTIC QUALITY INSPECTED 1**

## Final Report on

# DEFORMATION AND FRACTURE MECHANISMS IN THIN FILMS AND BERYLLIUM INTERMETALLICS

### Overview

The overall goal of this program was to investigate the mechanical properties of several Be intermetallics for the purpose of evaluating their suitability for high temperature structural applications. This work was begun May, 1989 and was completed in 1992 with Battelle Pacific Northwest Laboratories as the prime contractor and Washington State University as a subcontractor. At WSU the work was directed by Profs. John Hirth and Richard Hoagland. Subsequent work supported by this grant enabled the completion of the Ph. D. research of two students, Brad Benson and Sanjay Sondhi.

This program enabled the completion of research on the fracture toughness of thin films and the deformation behavior of  $Be_{12}X$  compounds. The grant enabled the extension of previous thin film work to include tests of thin brittle films on elastic-plastic substrates in order to measure the fracture toughness of the film and the film-substrate interface. The atomistic modelling had been focused on a study of the atomic arrangement in the core of several different types of dislocations in  $Be_{12}X$ . This work was extended to examine the energetics of the transformation of the bct  $Be_{12}X$  phase to the rhombohedral  $Be_{17}X_2$  phase by the repeated faulting. There is the potential that this deformation operation could produce a structure with enhanced plasticity.

### Fracture Toughness Measurements of Thin Films

A test method for measuring the toughness of attached thin films and the film-substrate interface was developed. The method involved deformation of the substrate under controlled displacement conditions using a test specimen that contains a thin panel of substrate coated with the film. Models of the test specimen allowed the determination of the crack driving forces as a function of the applied displacements and the crack length. The specimen and test is designed such that  $J$  decreases as the crack length increases. Thus the test method allows multiple measurements of film cracking, film decohesion, and film crack density saturation on a single specimen.

For Cr films ranging in thickness from 0.2 to 0.9  $\mu\text{m}$ , evaporatively deposited on Al and Cu substrates, the experiments indicate that the toughness of the Cr film varies approximately as the square root of thickness and were in the range of 2.5 to 4.5 MPa $\sqrt{\text{m}}$ . Also Cr films decohered from Cu substrates after film cracking, while they remained attached to Al substrates. The fracture energy of the Cr-Cu interface was found to be about 13 J/m<sup>2</sup>. The effects of substrate plasticity and stable decohesion cracking on the fracture toughness measurements was also examined.

### **Atomic Simulation of Dislocations in $\text{Be}_{12}\text{X}$ Compounds**

Earlier work in this part of the program involved the development of the relevant atomic potentials using the embedded atom method (EAM). These potentials were subsequently used to model various dislocations and stacking faults in the  $\text{Be}_{12}\text{X}$  bct structure by means of molecular dynamics calculations. One observation from this work concerned the transformation of the crystal structure from bct to base centered orthorhombic and to rhombohedral by a periodic operation of certain slip systems.

TEM observations of  $\text{Be}_{12}\text{Nb}$  that had undergone high temperature deformation had shown that  $a/2<100>$  and  $a/2<011>$  partials are present in very high densities and account for most of the plasticity. Associated with these two partials are stacking faults on the (001) and (011) planes. In our models we find that these faults have an very low energy. In addition, periodic faulting is possible on first the (001) and then (011) planes and this leads to localized phase transformation from the bct to a rhombohedral structure and thence to a base centered orthorhombic structure. The transformation from the bct  $\text{Be}_{12}\text{X}$  phase to the  $\text{B}_{17}\text{X}_2$  phase requires diffusion of Be atoms in addition to periodic faulting, thus suggesting the grain boundaries as preferential sites for the nucleation of the transformation. We suggest that alloying additions that favor the rhombohedral  $\text{Be}_{17}\text{X}_2$  structure would also favor this periodic faulting mechanism, and thus enhance ductility.

### **Theses Completed**

1. Bradley A. Benson, "A method for Fracture Toughness Measurements in Thin Films and Coatings" Ph. D. Thesis, Washington State University, 1993.

2. Sanjay K. Sondhi, "Atomic Scale Modeling of Dislocations in  $\text{Be}_{12}\text{X}$  Compounds", Ph. D. Thesis, Washington State University, 1994.